SCIENCE

FRIDAY, MARCH 18, 1898.

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Prof. J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE DEVELOPMENT OF ELECTRICAL SCIENCE. *

I.

IN a brief discourse on the development of electrical science little time can be given to the early history of the subject. This part is more or less familiar to all the members of the Academy, and hence it may be passed over by only such brief reference as may serve to recall to mind the more important of the early discoveries. The early Greeks have recorded some elementary phenomena now known to be electric, and it is probable that such knowledge was not uncommon, though little noticed. It is only in comparatively recent times that scientific research has taken the place of superstition and attempts have been made to classify and find reasons for the existence of all natural phenomena.

Beginning with the 17th century, probably the first investigator worthy of notice in this subject was Gilbert, of Colchester, who published his work entitled 'De Magnete' in 1600. Gilbert made systematic experiments and showed that the property of attracting light bodies could be given to a large number of substances by friction. He also showed that the success of the experiment depended largely upon the dryness of the body. These experiments gave rise

* Address of the President delivered before the annual meeting of the Indiana Academy of Sciences on December 29, 1897.

to the classification of substances as electrics and non-electrics. The true significance of Gilbert's observations as to the effect of moisture was not appreciated for a long time. Gilbert's list of electrics was added to by a number of other observers, prominent among whom were Boyle and Newton. The fact that light and sound accompany electric excitation was called attention to by Otto von Guericke, who also showed that a light body after being brought into contact with an electrified body was repelled by it.

Coming now to the 18th century, we find Hawkesbee in 1707 and Wall in 1708 speculating on the similarity of the electric spark and lightning. Then comes one of the most prominent experimenters of this century—Stephen Gray—who began to publish in 1720 and who in 1729 found that certain substances would not convey the charge of an electrified body to a distance. These experiments were the first to introduce the distinction between conductors and non-conductors, and, of course, very soon served to explain the reason why certain substances could not be electrified by friction when held in the hand. Gray also made the important discovery that the charge of an electrified body is proportional to its surface, and this was afterwards confirmed by the experiments of Le Monnier. Many of Gray's experiments were repeated and extended by Du Fay, who found that all bodies could be electrified by friction if they were held by an insulatory substance. Then came the improvements of the electric machine by Boze and Winckler; the firing of inflammatory substances, such as alcohol, by means of the electric spark by Ludolph, Gordon, Miles, Franklin and others. About this time (1745) the properties of the Leyden jar were discovered by Kleist, Cuneus and Muschenbroeck, and a few years later it was given practically its present form by Sir William Watson. Then follows one of the periods of exceptional activity in electrical research. A party of the Royal Society, with Watson as chief operator, made a series of experiments having for their object the determination of the distance to which electrical excitation could be conveyed and the time it takes in transit. They found among other things that several persons at a distance apart might feel the electric shock if they formed part of a circuit between the electrified body and a conductor such as the earth; also that the earth could be used to complete the circuit in Leyden jar discharges. They concluded that when two observers connected by a conductor, and at, say, two miles apart, obtained a shock by one touching the inside coating of a Leyden jar and the other the earth the electric circuit was four miles long, that is, the earth acted as a return conductor. They also concluded that the transmission was practically instantaneous. Watson had ideas as to electric fluids similar to those which were afterwards systematically worked out by Franklin. A great many curious and interesting experiments were made about this time, as, for example, the influence of electrification on the flow of water through capillary tubes as discovered by Boyle, the experiments of Mowbray on the effect of electrification on vegetation, and those of the Abbe Menon on the loss of weight of animals when they were kept electrified for a considerable time.

The effect of electrification on the flow of water has received considerable attention from eminent authorities in recent years, and that of the effect of electrification on the growth and composition of vegetable is at present attracting attention in the form of systematic investigation.

The contributions of Franklin are by far the most important which mark the middle portion of the 18th century. Franklin's experiments were begun about the middle of the year 1747, and seem to have been in-

spired by the receipt of a Leyden jar from a friend, Wm. Collinson, of London. He propounded the theory of positive and negative fluids, which has lately, in a modified form, been brought so prominently into notice again by the writings of Lodge, and he made an investigation of the principle of the Leyden jar, but the most important of his researches relate to the identification of electricity and lightning. The probable identity of the two phenomena had been hinted at, as we have seen, by several observers, but Franklin went systematically to work to test the hypothesis. Under date of November 7, 1749, the following passage is found in his note-book: "Electric fluid agrees with lightning in these particulars: (1) Giving light. (2) Color of the light. (3) Crooked direction. (4) Swift motion. (5) Being conducted by metals. (6) Crack or noise in exploding. (7) Subsisting in water or ice. (8) Rending bodies in passing through. (9) Destroying animals. (10) Melting metals. (11) Firing inflammable substances. (12) Sulphureous smell. The electric fluid is attracted by points; we do not know whether this property is in lightning. But since they agree in all the particulars wherein we can already compare them, is it not probable that they agree likewise in this? Let the experiment be made." The hypothesis was elaborated and sent to his friend Collinson, who communicated it to the Royal Society. This Society rather ridiculed Franklin's ideas at first, but his paper was published in London and also in France, and attracted considerable attention.

The experiment was first made in France by M. d' Alibard, at Marli, on May 10, 1752, and it was repeated shortly afterwards by M. de Lor, in Paris. The results of what were called the Philadelphia experiments were communicated to the Royal Society and caused quite a stir in scientific circles. It is right to say, with regard to the Royal Society, that Franklin's claims to scientific recognition were championed by Sir William Watson, and were fully endorsed by the Society by his election to a Fellowship and the award of the Copley Medal, together with the free donation of the Society's Transactions during his life.

Franklin's own experiments with kites are well known, as is also the method of protecting buildings from lightning which was introduced by him and is still very widely used, although it has been greatly abused by the lightning-rod man.

During the next decade Canton discovered the now commonly known difference between vitreous and resinous electricity. Beccaria experimented on the conducting power of water. Symmer made a number of interesting experiments on the electrification of different kinds of fabrics by friction, and propounded a theory of two electric fluids. Contemporaneous with these were a number of other experimenters who added to the stock of knowledge of this class of phenomena.

The experiments of Aepinus and others on the pyroelectric properties of tourmaline now began to attract attention. The experiments of the Abbé Haüy are perhaps the most important in this connection at this stage of the subject. He found the polar properties of the crystal and showed that similar properties were possessed by a number of other crystals. Aepinus made experiments in other branches of electricity, but he is chiefly noted for his ingenious single-fluid theory of electricity.

Between the years 1770 and 1780 the electrical organs of the torpedo were one of the principal topics of discussion. The experiments of Walsh and Ingenhousz were the first to definitely settle the character of the peculiar power of the fish.

The experiments of Cavendish belong to this period and were remarkable as being quantitative in their character. Consider-

ing the means at his command, the measurements made by this experimenter of the relative conducting powers of various substances must always excite admiration. Cavendish also proved the composition of water by causing different proportions of oxygen and hydrogen to unite by means of the electric spark.

We now come to the classical experiments of Coulomb, who established the law of the variation of the electric force with distance to be that of the inverse square, a law which had previously been inferred from experiments on spheres by Dr. Robinson, who, however, did not publish his results. Coulomb made an elaborate series of experiments on the distribution of electricity over charged conductors as influenced by shape and the proximity of other charged bodies. His theoretical and experimental work formed the basis of the mathematical theory as developed shortly afterwards by Laplace, Biot and Poisson, the work of the latter being particularly important.

Toward the end of the 18th century were made the important researches of Laplace, Lavoisier and Volta, and of Sausure in the electricity produced by evaporation and combustion. This is a subject destined to figure prominently again in the future, and in its rise there is in all probability involved the rapid decline in the importance of the steam engine. I should not be surprised if many of those present should live to see the steam engine practically a thing of the past.

In the 18th century also we must assign the discovery of Galvanic electricity, as the famous frog experiments were made in 1790. Practically no development was made, however, until Volta's work attracted the attention of the scientific world.

At the beginning of the 19th Century, then, we find the subjects of greatest interest were the discoveries of Volta and the invention of the voltaic pile. There followed almost immediately the discovery by Nicholson and Carlisle of the decomposition of water by the voltaic current. This discovery was followed a few years later by those of Sir Humphry Davy on the decomposition of the alkalies and the separation of metallic sodium and potassium. Thus the subject of electrolysis was fairly launched, and what it has grown to be we will see later.

Can there be some inter-relation between electricity and magnetism was now the query? The first positive answer seems to have been given by Romagnesi in a work published in 1805, but little or no notice appears to have been taken of this. Certainly no progress was made in the subject till 1820, when Oersted made his famous experiment before his class. By that experiment he proved that a wire carrying an electric current will, when properly placed, deflect a magnetic needle. The subject was almost immediately taken up by Ampere, and in a few months many of the important consequences which Oersted's discovery involved were developed. Ampere's work on the action of currents on currents and on magnets is classical and is still treated as part of the fundamental basis for the theory of electrodynamics. An account of his work may, therefore, be found in almost any of the numerous text-books on electricity. The conclusions reached by Ampere were confirmed by Weber by a series of much more refined experiments. To Weber also we owe improvements in galvanometers. The same year marks the discoveries by Arago that a current can not only deflect a magnet, but that it is capable of producing one by magnetizing steel needles.

The further discovery was made four years later by Sturgeon that soft iron although incapable of making a strong permanent magnet is yet much more susceptible to temporary magnetization by the electric current. Arago also made about

this time the important discovery that if a needle be suspended above a copper disc and the disc rotated the needle will be dragged round with the disc. This was not explained for some years, but seems to be the first discovery of induced currents.

These experiments mark the discovery of electro-magnetism, and began one of the most important eras in electrical discovery, the work which has been participated in by many eminent authorities. Among the many advances may be mentioned the experiments of Henry on the relative effects of different windings on the strength of an electro-magnet. He deduced the fact that the magnetizing action might be increased either by increasing the number of windings, the current remaining the same, or by increasing the current, the winding remaining the same. He pointed out the application of this to intensity and quantity arrangements of the battery, and also the importance of the intensity winding for the transmission of magnetizing power to a distance, as in telegraphy. The increased effect due to increasing the number of windings on the coil of a galvanoscope had been previously pointed out by Schweigger, and the discovery is embodied in Schweigger's galvanoscope.

In 1821 Faraday began his researches and many important discoveries were made by him. The main guiding idea in Faraday's work was the possibility of obtaining electricity from magnetism and in general the discovery of the inter-relation between the two. In this connection Arago's discovery of the rotation of a copper disc by the rotation of a magnet above it is of great importance, because, among other things, Faraday set himself to explain this. The result was the discovery of the commutatorless dynamo, or Faraday disc. In view of modern developments, probably the most important of Faraday's discoveries was that of the production of a current in a circuit when a current is either established or varied in strength in an adjacent circuit. This was followed by the discovery that relative motion of two circuits, one of which carried a current produced a current in the other, and that the motion of a magnet in the neighborhood of a circuit produced a current in the circuit. Another important discovery by Faraday was that of the quantitative laws which govern electrolytic decomposition, thus giving us our electrochemical equivalents.

At this time Lenz was led by experiment to the discovery of his celebrated law of induction, namely, that the current produced always in turn produces forces tending to oppose the change. For example, if a current be induced in a coil by bringing a magnet towards it the mutual action between the magnet and the current is to oppose the magnet's approach. This is important when looked at from the point of view of the conservation of energy or as an argument against perpetual motion. Lenz's law is, of course, when the actions are properly understood, a consequence of Newton's third law of motion.

Discoveries similar to those of Faraday as to induced currents were made almost simultaneously by Henry in this country. We have in the discoveries of Faraday and Henry the fundamental information required for nearly the whole of our recent developments in dynamo-electric generators and electric motors, but it was reserved for the next generation to develop them. This development we owe in no small degree to the spendid exposition of Faraday's discoveries and their consequences contained in Maxwell's book on electricity and magnetism.

Going back for a moment to 1822 we have to notice another important discovery, namely, the thermoelectric couple by Seebeck. There followed almost immediately the important experiment of Cumming, who

showed that the thermoelectric order of the metals is not the same at all temperatures.

The next important discovery in thermoelectricity was that of Peltier, of the heat generated at the junction of two metals when a current is forced across it against the e. m. f. of the junction. In later years we have the classic researches of Thomson (Kelvin), who added thermoelectric convection and the specific heat of electricity and gave the thermoelectric diagram method of representing results. This method was afterwards used and extended by Tait, who added a good deal to our knowledge of thermoelectric data. Among the large number of others who have worked in this field we may mention Becquerel, Magnus, Matthieson, Leroux and Avenarius. Thermoelectric batteries of considerable power have been made by Clamond and others.

In 1827 the celebrated law giving the relation between e. m. f. resistance and current was published by Ohm in a paper on the mathematical theory of the galvanic circuit. The theory has been sometimes criticised, but there seems to be absolute certainty that the law is almost exact, and it has proved of the greatest importance in the further development of the subject of electric measurements.

The subject had about the middle of the century reached a stage in which it was possible to develop almost completely the mathematical theory as we now have it. Most of the work since Faraday's time has been directed towards quantitative measurements and the furnishing of exact data to answer questions as to how much in various cases. F. E. Neumann discovered what he called the potential function (now called the coefficient of self and mutual induction) of one current on another and on itself and succeeded in giving a theory of induction which was in accordance with the experimental laws. The laws were afterwards experimentally verified by Weber. In 1849 the experiments of Kirchoff on the absolute value of the current induced in one circuit by another, and in the same year Edlund's experiments on self and mutual induction, are important. In 1851 Helmholtz gave a mathematical theory of this part of the subject, which he supplemented with an experimental verification.

One of the most important of the series of experiments made by Henry was on the oscillatory character of the discharge from a Leyden jar. This he discovered from the effect of the discharge on a steel needle surrounded by a coil, through which the current was made to pass. The results of these experiments were communicated to the A. A. A. S. in 1850, but he knew of the effect much earlier, certainly in 1841. Previously the anomalous behavior of the discharge of a jar when used to magnetize steel needles had been noticed, but was attributed, as I believe, to some peculiarity of the steel. Henry was the first to appreciate the true reason, although he could hardly at that time be expected to see the great importance of his discovery.

Helmholtz, in 1847, suggests that the discharge of Leyden jars may be of the nature of a backward and forward movement. There is a curious parallelism in the work of several investigators about this time, and particularly in that of Hemholtz and Thomson. In the *Philosohphical Magazine* for 1855 there is paper by Professor W. Thomson (Kelvin) in which the theory of the discharge of a Leyden jar is discussed and the prediction made that under certain specified conditions the discharge must be oscillatory. A number of similar papers, going back to 1848, treat of similar subjects. Henry's results do not appear to have become generally known, and we find the verification of Thomson's prediction in 1857 by Feddersen. A number of other physicists have investigated the subject, the work of Schiller being of particular

value. The recent applications will be referred to later.

The mathematical theory of electrostatics and magnetism was greatly extended about this time by Thomson and others, and received its most complete statement at the hands of Maxwell in his papers read before the Royal Society and in his book, published in 1873, but still the standard of reference. Very little has since been discovered which was not foreshadowed by Maxwell's theory or contained in his equations, which have been found general enough to cover almost everything, although experiment has generally been necessary to suggest the consequences of the theory.

The practical applications of electricity have played a most important part in the development of the subject during the last sixty years. Indeed, a great part of the work of these years has had some practical application in view. One of the first of these practical applications was that of telegraphy.

The telegraph, being one of the earliest of the practical developments, naturally had a great effect in stimulating the advance in knowledge of electricity, and hence I give a somewhat fuller sketch of the early history, that space will permit for the later applications.

The discovery of Stephen Gray, in 1829, that the electrical influence could be conveyed to a distance by means of an insulated wire, is probably the first of direct influence in connection with telegraphy. As a result of this discovery and the investigations which followed it, a considerable number of proposals were made as to the use of the electrical force for the transmission of intelligence. The first of these of which I have found any record was made in 1753 by Charles Morrison, a Scotchman, and then followed other proposals for electrostatic telegraphs by Bozolus in 1767, by Le Sage in 1774, by Lomond in 1787, by Betancourt in the same year, by Reizen in 1794, by Cavalla in 1795 and by Ronalds in 1816.

The discovery of voltaic electricity, and most directly the discovery of Nicholson and Carlisle of electrolysis gave rise to another group of proposals for the application of this discovery to the production of telegraphy. Among those may be mentioned that of Sömmering in 1809, of Coxe in 1810 and of Sharpe in 1813. In more recent years, of course, the same application appears in the chemical telegraphs, some of which are capable of giving very satisfactory results and great speed.

The discovery which had the greatest influence on the development of telegraphy was that of Oersted, supplemented by the work of Schweigger and Ampere. Ampere proposed a multiple-wire telegraph with galvanoscope indicators in 1820, and a modification was constructed by Ritchie. A single-circuit telegraph of this character was invented by Tribaoillet, but didn't come into use. In 1832 Schilling's five-needle telegraph appeared, and he, also, used a single-needle instrument, but his early death stopped further progress. In 1833 Schilling's telegraph was developed, to some extent, by Gauss and Weber, who used it for experimental purposes. The following quotation, referring to Gauss and Weber's telegraph, from *Poggendorf's Annalen*, is of considerable historical interest:

"There is, in connection with these arrangements, a great and until now in its way novel project, for which we are indebted to Professor Weber. This gentlemen erected, during the past year, a double-wire line over the houses of the town (Göttingen), from the Physical Cabinet to the Observatory, and lately a continuation from the latter building to the Magnetic Observatory. Thus, an immense galvanic chain is formed, in which the galvanic current, the two multipliers at the ends being included, has to travel a distance of nearly

9,000 (Prussian) feet. The line wire is mostly of copper, of that known as 'No. 3,' of which one metre weighs eight grammes. The wire of the multipliers in the Magnetic Observatory is of copper, 'No. 14,' silvered, and of which one metre weighs 2.6 grammes. This arrangement promises to offer opportunities for a number of interesting experiments. We regard, not without admiration, how a single pair of plates, brought into contact at the farther end, instantaneously communicate a movement to the magnetic bar, which is deflected at once for over a thousand divisions of the scale," Further on in the same paper: "The ease with which the manipulator has the magnetic needle in his command, by means of the communicator, had a year ago suggested experiments of an application to telegraphic signalling, which, with whole words and even short sentences, completely succeeded. There is no doubt that it would be possible to arrange an uninterrupted telegraph communication in the same way between two places at a considerable number of miles distance from each other."

The method of producing the currents in Gauss' and Weber's experiments was an application of the important discoveries of Faraday and Henry, above referred to, in the induction of current by currents and by magnets.

On the recommendation of Gauss, this telegraph was taken up by Steinheil, who, following their example, also used induced currents. The important contributions of Steinheil were the discovery of the earth return circuit, the invention of a telegraphic alphabet and a recording telegraph. Steinheil contributes an account of his telegraph to Sturgeon's Annals of Electricity in which the relative merits of scopic, recording and acoustic telegraph are discussed, and the advantages, which experience has since brought into prominence, of the acoustic form are pointed out.

Schiller's telegraph was exhibited at a meeting of German naturalists held at Bonn in 1835, and was there seen by Professor Muncke, of Heidelberg, who, after his return to Heidelberg, made models of the telegraph and exhibited them in his classroom. These models were seen by Cooke in the early part of 1836, and gave him the idea of introducing the electric telegraph in England. Cooke afterward became associated with Wheatstone, and a large number of ingenious arrangements for telegraphing was the result. Many of the later developments by Wheatstone are still in use and are hard to beat.

Steinheil appears to have been anticipated in the idea of making the telegraph self-recording by Morse, who, according to evidence brought forward by himself, thought out some arrangements as early as 1832. Exactly what Morse's first ideas were seems somewhat doubtful, and he did nothing till 1835, when he made a rough model of an electro-magnetic recording telegraph. Morse's mechanical arrangements were of little merit, and his alphabet and method of interpretation by a dictionary were clumsy and inconvenient. The chief point of interest in connection with the early history of the Morse telegraph was the proposal to make use of Sturgeon's discovery of electro-magnetism of soft iron. Morse, however, seems to have known practically nothing of the subject except that iron could be magnetized by a current, and in consulting his colleague, Dr. Gale, he was unwittingly led to use the discoveries of Henry, who had previously practically solved the whole problem. Much of the subsequent improvement in the mechanical arrangements were due to Vail, who became associated with Morse, and the Morse code as we now know it was almost, if not entirely, worked out by Vail. Considerable dispute and some litigation arose over Morse's claims, but that is outside our

present subject. There is no doubt that the electric telegraph was a slow-growth invention, with a view to pecuniary and other advantage, being ever ready to lay hold of each scientific discovery and try to turn it to account. The question who first conceived the idea can never be satisfactorily answered.

After 1840 there is little to record of a purely electrical character bearing only on telegraphy, but there have been many very ingenious mechanical contrivances introduced for recording signals, for reproducing pictures and handwriting and for printing, for duplexing, quadruplexing and multiplexing telegraph lines, for increasing the rate of signaling and in many ways increasing the expedition with which messages can be sent. Of course, the success of many of these contrivances, and even their invention, depended upon an increased knowledge of the laws of electricity and magnetism. For example, effective duplexing, quadruplexing, etc., depends on a proper understanding of the electrostatic capacity of the line, and this was not understood properly until the mathematical investigations of Thomson and others cleared the matter. For the impetus towards discovery in this direction again we are largely indebted to telegraphy, for much of that class of work was suggested by the difficulties encountered in signalling through long submarine cables.

The invention of the telephone is fast becoming ancient history, and yet it will always mark one of the greatest of the useful applications of electricity. It does not call for more than a passing remark here, because electro-magnetically it is all in Faraday's and Henry's papers.

The radiophone should be mentioned because it marks the application of the discovery, by May and Smith, of the effect of light on the resistance of selenium. This effect has since been found in the case of a large number of other substances, but it is still an interesting field for research. A number of experiments on this subject have been associated with attempts to make things visible at a distance. No doubt it will ultimately be possible not only to talk to a distant party, but also to see the party talked to, and thus, as it were, look the party with whom you are conversing in the eye.

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(*To be concluded.*)

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*THE PROVINCE AND PROBLEMS OF PLANT PHYSIOLOGY.**

THE exploitation and survey of the flora of our continent is a task of such tremendous magnitude that it has consumed the greater portion of the energy of American botanists until within a few years of the present time. The constantly increasing number of workers attracted to the subject has made possible not only a more thorough organization of the interests of taxonomic botany, but has also permitted a great deal of attention to questions of general morphology and cytology. Within the last decade an awakening interest has been shown in subjects in the physiology of plants. This interest has been manifested by the introduction of physiological matter in the text-books on botany, by the organization of courses of instruction in this branch in some of the more prominent colleges and universities, and by the accomplishment of investigations of more or less importance.

Any subject is liable to misconception and misapprehension during the earlier stages of its introduction into any country, and plant-physiology in America is no exception to the probability.

A misapprehension of a subject is likely to be followed by a perversion of the facilities devoted to it, the neglect of its

* Read before the Minnesota Academy of Science, December 30, 1897.